intensity is approximately the same in each gas for any particular type of rays.

In conclusion, I wish to acknowledge my indebtedness to Prof. Sir J. J. Thomson for his kindly interest and helpful suggestions throughout the course of the investigation.

Fluorescent Röntgen Radiation from Elements of High Atomic Weight.

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A considerable amount of work has been done by various experimenters* showing that, when an element of higher atomic weight than calcium is subjected to a suitable primary beam of X-rays, the rays which leave the radiator consist of two types: firstly, the purely scattered radiation, which is almost exactly similar to the incident beam, and, secondly, a characteristic homogeneous radiation. The scattered radiation which in the case of a primary beam from an X-ray bulb is heterogeneous, is, with elements of low atomic weight, quite small in intensity when compared with the intensity of the homogeneous radiation which is emitted simultaneously. Owing to this fact, it is comparatively easy to prove that the elements with atomic weights between that of calcium and cerium give off when stimulated with X-rays homogeneous beams, and the hardness of the characteristic radiation from each of these elements has been measured by determining the absorption in aluminium. The radiations are usually defined by the value of their absorption coefficients, that is, by λ/ρ where $I = I_0 e^{-\lambda x}$; ρ = density of aluminium. Using the values obtained, it is possible to plot a curve showing the relation between atomic weight and λ/ρ for the elements which emit a characteristic radiation, taking atomic weight as abscissa and λ/ρ for ordinates. If this is done, it will be found that the elements with atomic weights between that

* Barkla and Sadler, 'Phil. Mag.,' Oct., 1908; Chapman, 'Phil. Mag.,' April, 1911; Barkla, 'Phil. Mag.,' Aug. 1910.

of calcium and cerium lie on an approximately smooth curve (Group K). When, however, the elements with higher atomic weight than silver are examined under suitable conditions, it is found that, with these elements, there are two distinct types of radiation: one, a hard characteristic radiation such as belongs to Group K, and superposed on this a very soft radiation. Prof. Barkla and Mr. Nicol* have investigated the soft radiations from the elements silver, antimony, iodine, and barium, and have shown that these elements, in addition to the usual characteristic radiation, emit another very soft radiation, which is also characteristic of the element. The values of the λ/ρ for these elements have been determined, and it has been shown, as far as it is possible with such soft rays, that they are homogeneous. If these values are plotted on the same diagram as that mentioned above, a second short curve is obtained, which can be continued to the X axis; when this is done, if this second curve resembles in shape the curve for Group K, it will pass before it reaches the X axis through the region of atomic weights between 184 and 238, which contains tungsten, gold, platinum, lead, bismuth, thorium, and uranium. This second series of elements has been designated Group L. Up to the present it has been impossible to draw this curve with any accuracy, as none of the elements between tungsten and uranium have been investigated as regards their X-ray properties.

The following experiments were performed in order to see—

(1) Whether the radiations emitted by these elements when the scattered radiation was allowed for, were as homogeneous as those emitted by the elements of Group K.

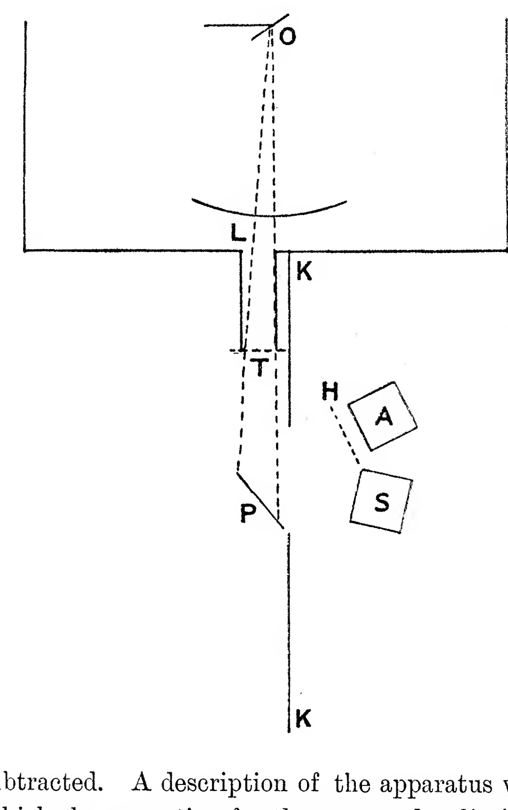
(2) To investigate whether the same absorption phenomena are found with the elements of Group L as with Group K.

(3) To investigate whether there is an empirical relation between atomic weights of different elements emitting characteristic radiations of the same penetrating power as tested by the absorption coefficient.

The chief difficulty which has to be met, when examining the X-radiation from the elements in the second group (Group L), is the magnitude of the scattered radiation, this being heterogeneous, depending on the primary beam; it is, unless special precautions are taken, impossible to distinguish it from the supposed homogeneous radiation which it accompanies. With elements of atomic weight such as copper, the intensity of the scattered radiation is so small (sometimes less than 0·5 per cent. of the total radiation) that it can for all practical purposes be neglected, but, as the atomic weight rises, the intensity of the scattered radiation increases, for two reasons: firstly, for the same number of atoms present, there is a greater mass of

* 'Lond. Phys. Soc. Proc.,' Dec., 1911, vol. 24, part 1.

scattering material; and, secondly, sufficient evidence has been obtained to show that the ordinary law of scattering of mass for mass the same, which has been shown to hold for all elements up to sulphur, ceases to be true when the heavier elements are considered. In a recent paper, Prof. Barkla* estimated that copper scatters about twice as much radiation as an equal mass of one of the lighter elements, such as sulphur, while it would appear that silver is six times as efficient a scatterer as sulphur, mass for mass. This difficulty, which begins to enter, even in Group K, with silver, will, with elements of atomic weight of the order of 200, enter to such an extent that if the radiation from an element of high atomic weight such as platinum was examined in the ordinary way, the great increase of scattered radiation would mask, if it did not completely swamp, any characteristic radiation which might be present. The method of attacking this difficulty was to so arrange the experiment that the intensity of the purely scattered radiation could be



measured and subtracted. A description of the apparatus will serve to show the manner in which the correction for the scattered radiation was made.

X-rays from the anticathode O passed through the slit L in the lead box

* Barkla, 'Phil. Mag.,' Sept., 1911.

on to the radiator in the position P. The radiation leaving the plate P passed through another adjustable slit in the lead screen KK, into the two electroscopes A and S. In front of the electroscope A was placed a stand in which the absorbing sheets were placed when the radiation was tested. The electroscope S simply served to standardise the intensity of the secondary radiation from the plate P. In order to limit the primary beam so that it fell almost wholly on the radiator P, the rays from the bulb were made to pass through a narrow lead tunnel, and at the end of this tunnel at T sheets of thick aluminium were placed so as to cut off all but the very hard radiation which is present in the beam. A factor which enabled the scattered radiation to be minimised, and which has perhaps not received the importance it should, is the advantage derived from using thin radiators. For, generally speaking, the homogeneous radiation, owing to its low penetrating power, comes only from a small depth. Any greater thickness than this depth does not serve to increase the intensity of the homogeneous radiation but merely increases the scattered radiation which is able to come from deeper layers. In these experiments very thin radiators were used but they were in all cases of sufficient thickness as to be considered of infinite depth from the point of view of the homogeneous radiation.

The ordinary method of determining the successive absorptions was used. The deflection in the electroscope A was first determined while the standardising electroscope underwent a certain deflection; a sheet was then placed in the stand H so as to absorb a portion of the rays passing into A, and the leak in A while the standardising electroscope suffered the same deflection was measured. From these values the percentage absorption of the radiation by each sheet was measured.

The method of subtracting the merely scattered radiation was as follows:—The bulb was worked until it was exceedingly hard with an equivalent spark gap of 5 or 6 inches. In addition to this the primary beam was made to pass through a thick sheet of aluminium (0·2 cm.) placed in the path of the beam at T; in this way all but the hardest constituent of the beam was stopped by the aluminium, thus a beam of X-rays of very great hardness was obtained. This penetrating primary when it fell on the radiator at P made it emit a radiation which consisted of (1) the supposed homogeneous constituent, (2) the superposed scattered radiation. This heterogeneous beam was then examined in the usual way; the effect of placing the sheets of aluminium in front of the electroscope A was to cut down the supposed homogeneous radiation, which was, of course, soft when compared with the scattered radiation for the elements experimented on in Group L. On the other hand, owing to its great penetrating power, the scattered radiation was

not cut down to any great extent; in the case of gold, aluminium of thickness sufficient to cut off 99·9 per cent. of the homogeneous radiation, did not cut down the scattered radiation more than 10 per cent. When these successive absorptions had been taken, a thickness of aluminium (0·13 cm.) was placed in the stand H; this cut off, for all practical purposes, the whole of the homogeneous radiation. At the same time almost the whole of the hard scattered radiation still reached the electroscope. With this arrangement the amount of the superposed scattered radiation was measured by allowing the standardising electroscope to suffer the same deflection as in the previous absorption experiments, and noticing the deflection which the leak, due to the scattered radiation, produces in the electroscope A. From these values the total intensity of the scattered radiation can be readily found. If this constant factor is subtracted from the previous values, results are left which give not the absorption of the whole beam consisting both of scattered and homogeneous rays, but now only the absorption of the supposed homogeneous radiation. A typical account of this scattering correction is given in detail for the platinum radiation, for the other elements a correction of the same order has been made and the final results are stated.

Correction for the Scattered Radiation from Platinum.

The first column in the table below shows the number of sheets in front of the electroscope A, the second column the intensity of the total radiation (*i.e.*, scattered and homogeneous) after each successive absorption. The third column represents the intensity of the total radiation *minus* the scattered radiation, obtained by subtracting the scattered radiation as shown below:—

No. of absorbing sheets, each 0·0067 cm.	Intensity of total radiation (scattered + homogeneous).	Intensity of homogeneous radiation (total − scattered radiation).
0	54·6	50·1
1	38·3	33·8
2	27·5	23·0
3	20·1	15·6
4	15·2	10·7
5	11·7	7·2

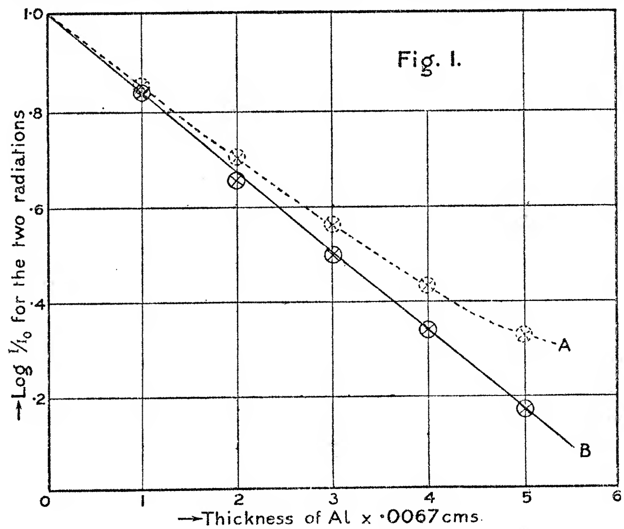
Intensity of the scattered radiation as measured by passing the beam from the platinum radiator through 0·13 cm. of aluminium, which absorbs 99·9 per cent. of the homogeneous radiation and only 9·8 per cent. of the scattered radiation = 4·1.

Adding to 4·1 the 10 per cent. of the scattered radiation which is absorbed in the aluminium,

Total intensity of scattered radiation = 4·5.

Subtracting this as a constant factor from the values in Column 2, Column 3 is obtained.

If, now, $\log (I_0/I)$ for the total radiation from Column 2 and $\log (I_0/I)$ for (total radiation − scattered radiation) from Column 3 be plotted against thickness of aluminium absorbing, fig. 1 is obtained. It will be seen that the curve which represents the absorption of the total radiation becomes a



straight line when the scattered rays are allowed for. That is, when the superposed scattered radiation is subtracted, there is left a homogeneous beam.

Results showing the Homogeneity of the Radiations.

To measure the homogeneity of the rays from the various elements they were passed through plates of aluminium of different thicknesses and the percentage absorption of the emergent rays measured by a sheet of aluminium. In the tables below, the first column gives the percentage absorption of the rays by the different plates of aluminium; the second, the value of the percentage absorption of the emergent rays by aluminium (0·0067 cm.).

Tungsten.

Radiator .... Powdered tungsten metal.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0067 cm.).
16	43·8
50	41·9
70	39·9
82	38·0
89	39·9
Mean value..............	40·7

$\lambda/\rho = 30{\cdot}0$.

Platinum.

Radiator .... Pure platinum foil.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0067 cm.).
15	32·5
42	31·9
61	32·2
73	32·2
82	32·7
Mean value..............	32·3

$\lambda/\rho = 22{\cdot}2$.

Gold.

Radiator .... Pure gold plate.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0067 cm.).
12	31·3
40	33·2
59	31·5
72	29·9
81	31·6
Mean value..............	31·5

$\lambda/\rho = 21{\cdot}6$.

Lead.

Radiator .... Pure lead foil.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0067 cm.).
12	25·6
35	26·3
52	25·8
65	25·8
74	27·8
81	26·0
86	26·0
Mean value..............	26·2

$\lambda/\rho = 17{\cdot}4$.

Bismuth.

Radiator .... Powdered bismuth metal.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0067 cm.).
10	23·7
32	24·2
49	24·5
62	24·5
72	24·3
79	25·0
Mean value..............	24·4

$\lambda/\rho = 16{\cdot}1$.

Thorium.

Radiator .... Powdered thorium oxide.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0134 cm.).
5	24·6
29	25·7
46	24·4
59	25·1
69	25·5
Mean value..............	24·3

$\lambda/\rho = 8{\cdot}0$.

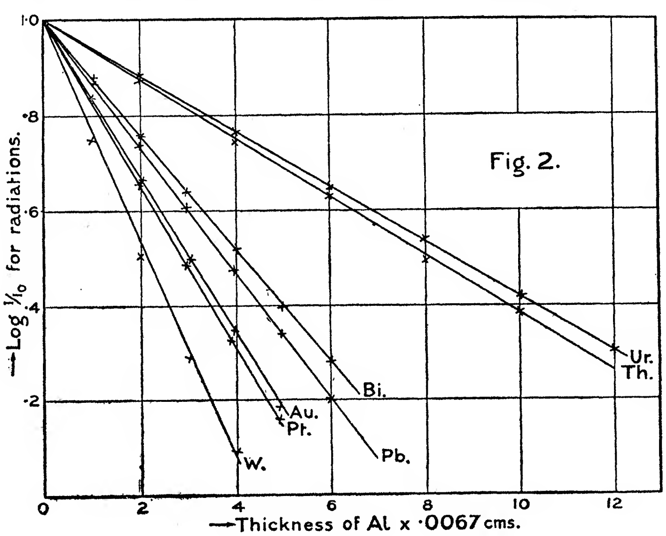
Uranium.

Radiator .... Powdered uranium oxide.

Percentage absorption of rays by different plates of Al.	Percentage absorption of the emergent rays by Al (0·0134 cm.).
4	24·9
26	22·6
43	23·2
56	23·3
66	23·1
74	23·1
Mean value..............	23·1

$\lambda/\rho = 7{\cdot}5$.

The relation between the thickness of aluminium absorbing and $\log(I/I_0)$ at each successive absorption is plotted in fig. 2 for the whole series of radiations, from the tables just given. The straight lines obtained indicate the almost exact homogeneity when the scattered radiation is subtracted.



Relation between the Atomic Weights of Elements Emitting same Characteristic Radiation.

If a curve be plotted with λ/ρ for ordinate and atomic weight as abscissa for these elements, it will be seen that the points so obtained lie on an approximately smooth curve.

The determination of the values of λ/ρ for so many elements in Group L has revealed an interesting relation, similar to that pointed out by Whiddington,* between the atomic weights of two elements which, though belonging to different groups, can be caused to emit the same characteristic radiation. If W_L represents the atomic weight of an element in Group L that gives out a radiation having a certain penetrating power as measured by the λ/ρ in aluminium, and W_K is the atomic weight of an element in the first group (K), which, if it existed, would give out the same radiation (this is obtained from the curve mentioned at the commencement of the paper), then it will be found that in all cases the relation between W_L and W_K is expressed almost exactly by the empirical formula—

$$W_K = \tfrac{1}{2}(W_L - 48).$$

This is shown for all elements from tungsten to uranium in the following table, which explains itself:—

Element in second group (Group L).	λ/ρ.	Atomic weight of element in Group L, W_L.	Atomic weight of element in Group K, which, if it existed, would emit the same characteristic radiation.	
			Value from curve, experimental.	Value calculated from formula $W_K = \frac{1}{2}(W_L - 48)$.
Tungsten	30·0	184·0	69·7	68·2
Platinum	22·2	195·0	75·2	73·5
Gold	21·6	197·2	75·5	74·6
Lead	17·4	207·0	79·8	79·5
Bismuth	16·1	208·5	80·7	80·2
Thorium	8·0	232·0	91·4	92·0
Uranium	7·5	238·0	93·2	95·0

It is impossible, at present, to state what is the physical significance of this formula, but it is most useful in determining the absorption coefficients of elements directly from their atomic weights.

Selective Absorption by Elements of Group L.

The elements belonging to Group K exhibit another leading characteristic. This is that any particular element in Group K shows a selective absorption

* 'Nature,' November 30, 1911.

for radiations which have a penetrating power just greater than its own. Thus if the coefficient of absorption of an element X in Group K, such as copper, be measured for the various homogeneous beams from calcium to cerium, when the radiation absorbed is soft the absorption in X is considerable, but as the radiation is made more penetrating the absorption in aluminium and in the element X diminishes proportionately. When, however, the radiation which is being absorbed is made more penetrating than the secondary characteristic of the metal X, the absorption in X first ceases to diminish as rapidly as the absorption in aluminium, then it increases, and it is at this point of increase that the characteristic radiation of the element X is excited. As the primary beam becomes still more penetrating, the absorption in the element X begins to diminish, and eventually the absorptions in aluminium and the metal X diminish proportionately.

In order to show that the same phenomena take place with the elements of Group L, the absorption of thin layers* of lead oxide and bismuth carbonate for a series of homogeneous beams belonging to Group K was measured. The percentage absorptions by the thin layers of the two salts were determined for the characteristic radiations from copper, zinc, arsenic, selenium, bromine, strontium, molybdenum, silver, and tin. It was impossible to use the pure elements lead and bismuth, owing to the difficulties of obtaining thin enough layers for absorbing sheets. On this account only relative values of the absorption coefficients have been determined, but these serve to show all that is necessary.

In the following tables the first column shows the radiation absorbed, the

Absorption by Lead Oxide.

Secondary radiator.	Absorption in Al. Absolute λ/ρ.	Absorption in Pb. $k\,(\lambda/\rho)$.	$\frac{\text{Absorption in Pb}}{\text{Absorption in Al}}$, $= k^{-1}$ times value below.
Copper	47·7	269	5·6
Zinc	39·4	224	5·7
Arsenic	22·5	140	6·2
Selenium	18·9	129	6·9
Bromine	16·3	126	7·7
Strontium	13·0	161	12·4
Molybdenum	4·7	143	30·0
Silver	2·5	84	34·0
Tin	1·57	63	40·0

k is of the order unity.

* These layers were made by mixing the salt in question with a small amount of pure gum; the absorption of a thin layer of the paint so formed was then measured. In this way it was impossible to obtain exactly even thicknesses of the salt, so that an error is

Absorption by Bismuth Carbonate.

Secondary radiator.	Absorption in Al. Absolute λ/ρ.	Absorption in Bi, relative. $k'(\lambda/\rho)$.	$\frac{\text{Absorption in Bi}}{\text{Absorption in Al}}$, $= k'^{-1}$ times value below.
Copper	47 ·7	277	5 ·8
Zinc	39 ·4	238	6 ·0
Arsenic	22 ·5	152	6 ·8
Selenium	18 ·9	134	7 ·0
Bromine	16 ·3	117	7 ·0
Strontium...........	13 ·0	165	12 ·7
Molybdenum	4 ·7	147	31 ·3
Silver	2 ·5	87	34 ·9
Tin	1 ·57	66	42 ·0

k' is of the order unity.

second the absorption in aluminium for this radiation, the third the relative absorption in the salt.

The two following curves show graphically the relation between absorption in aluminium and the relative absorption in lead and bismuth. The

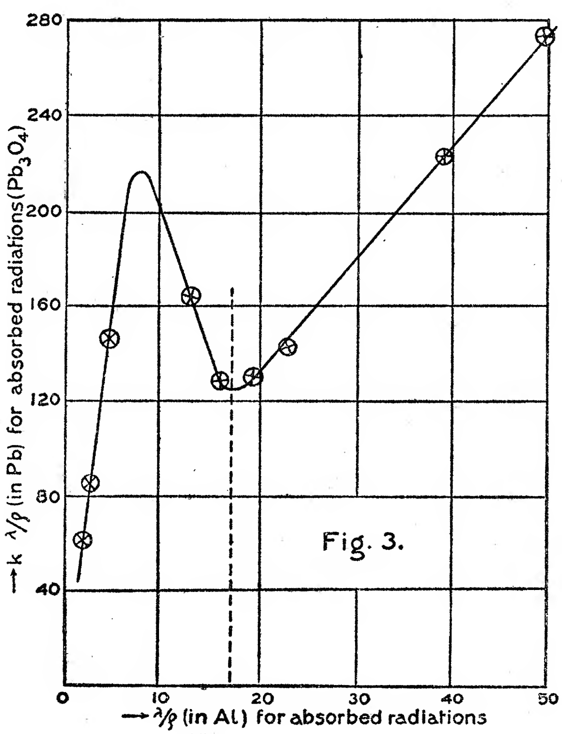


Fig. 3.

introduced in the determination of λ/ρ. Owing to this, no correction has been applied for any slight lack of homogeneity of the rays from the several elements which served as radiators.

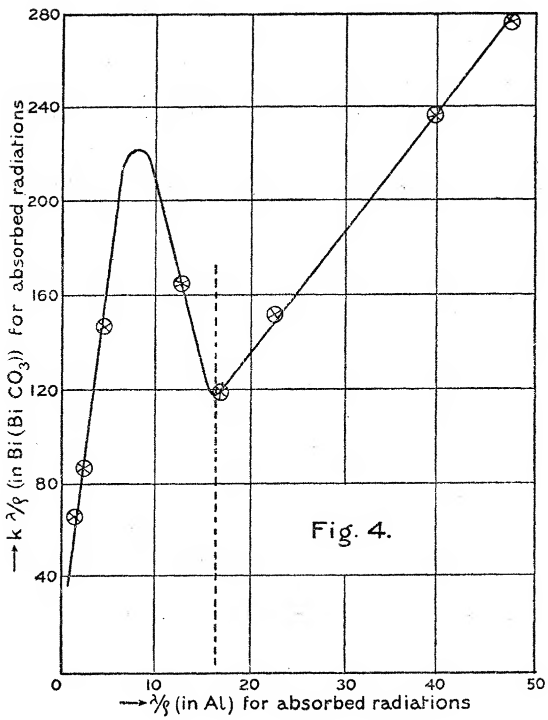


Fig. 4.

absorption by the light elements in the two salts is practically negligible when the relation between the relative masses and the absorption coefficients of the light and heavy elements are considered, so that the values obtained show within the limits of error of the experiment the absorption in lead and bismuth.

It will be seen that the shape of both curves is similar in its general features to that obtained for elements of Group K. In these curves the dotted lines show the point at which the characteristic radiation is excited. This can be found directly from the known values of λ/ρ for the homogeneous radiations from lead and bismuth, or it can be calculated from the empirical formula. The results demonstrate that the lead radiation ($\lambda/\rho = 17{\cdot}4$) is excited between the elements selenium ($\lambda/\rho = 18{\cdot}5$) and bromine ($\lambda/\rho = 16{\cdot}4$), whereas bismuth ($\lambda/\rho = 16{\cdot}1$) is excited between bromine ($\lambda/\rho = 16{\cdot}3$) and strontium ($\lambda/\rho = 13$). Thus these elements of Group L exhibit the same absorption phenomena as elements of Group K, in so far as they need a more penetrating radiation than themselves to be the exciting source.

Summary.

The results of these experiments show that there is a whole group of elements (Group L), containing tungsten, gold, platinum, bismuth, and the radioactive elements thorium and uranium, which emit when suitably excited secondary homogeneous Röntgen radiations similar in type to those emitted by the elements of the ordinary Group K. Their homogeneity has been demonstrated by a method which allows the scattered radiation to be subtracted. The values of the absorption coefficients in aluminium have been determined.

An empirical relation exists between atomic weights (W) of two elements which are in different groups, but which give out the same characteristic radiation. It is expressed by the formula

$$W_K = \tfrac{1}{2}(W_L - 48).$$

This relation holds for all the elements in Group L within the limits of experimental error.

It has also been shown that the elements of Group L exhibit the same selective absorption phenomena in the neighbourhood of an absorption band. The values given are for lead and bismuth. These results would go to show that the mechanism of production and the type of the radiations of both groups are the same, but further experiments are still necessary to show that there is an exact similarity.

In conclusion my best thanks are due to Prof. Sir J. J. Thomson for his kind interest in these experiments.